Status of the New g-2 Experiment at Fermilab

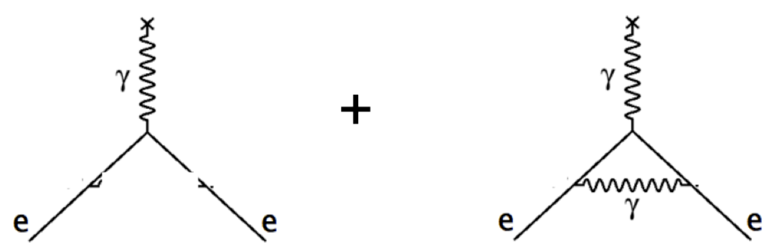
Mandy Rominsky
Fermilab

What is g-2?

- Magnetic moments: Fundamental property of a particle
- The spin and magnetic moment are related by:

$$\vec{\mu} = g_s \left(\frac{q}{2m} \right) \vec{s}$$

- Lande factor (g): Predicted to be 2, but found experimentally to be > 2
  - Radiative corrections



Anomalous Magnetic Moments

- Define

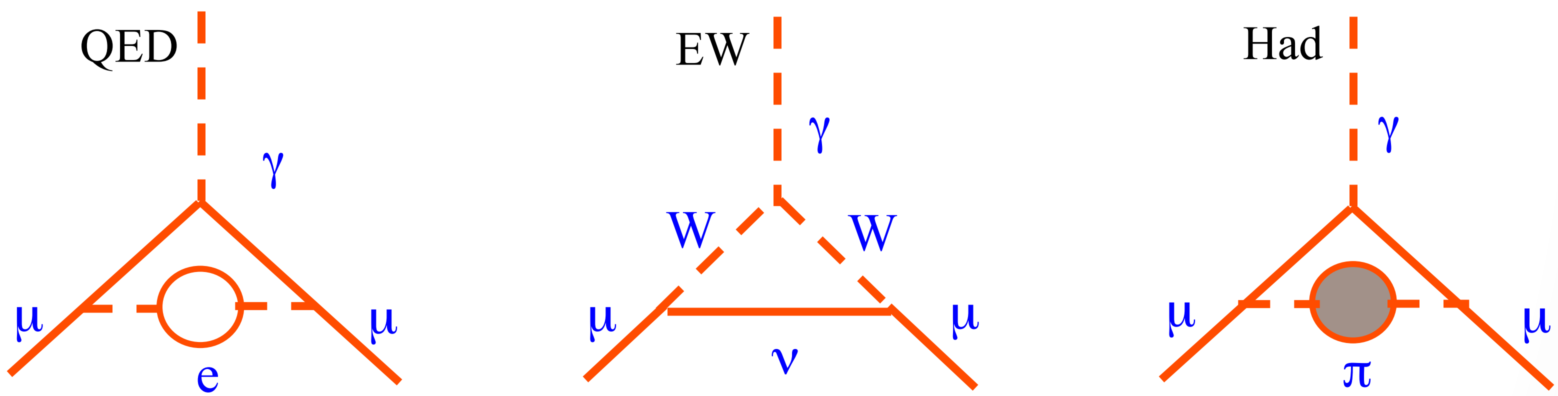
$$a = \frac{g-2}{2}$$

- Current value of electron: $a^{exp}_{e} = 1159652180.73 (28) \times 10^{-12}$
  - Hanneke et al, PRL100(2008) 120801
- Agrees with the Standard Model
  - $a^{Th}_{e} = 1159652181.78(77) \times 10^{-12}$

g-2 and Theory Calculations

- Break the Standard Model prediction into components:

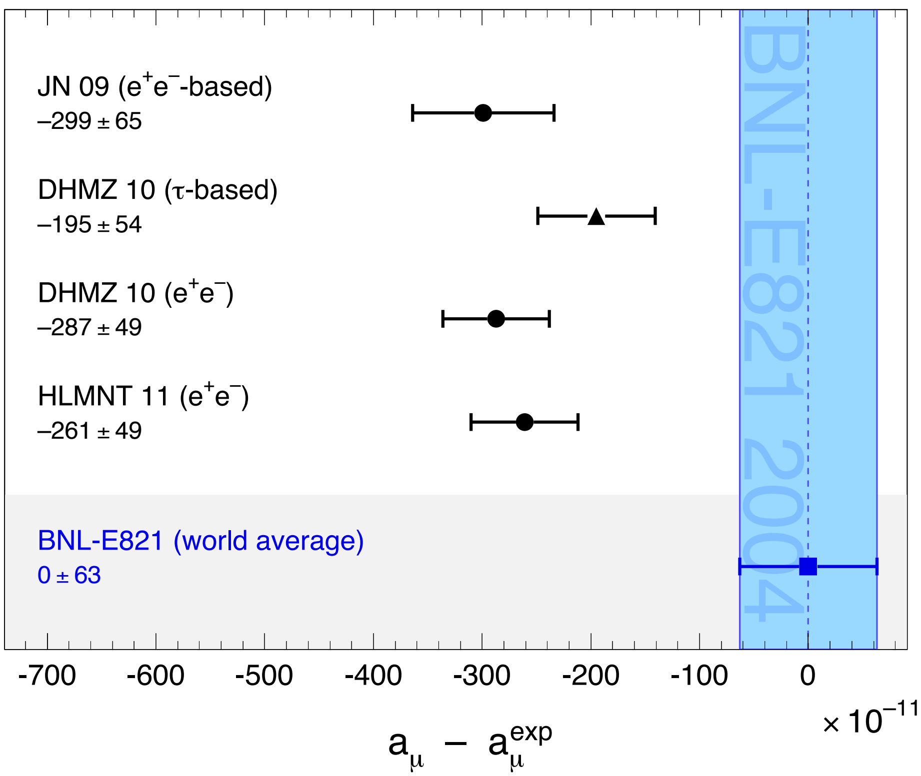
$$a_\mu^{SM} = a_\mu^{QED} + a_\mu^{Weak} + a_\mu^{Had}$$



SM Prediction: $a_\mu^{SM} = 116\ 591\ 802\ (49) \times 10^{-11}$

Theoretical vs Experimental Values

- $a_\mu^{exp} = 116\ 592\ 089\ (63) \times 10^{-11}$
  - Most recent result from BNL
- $a_\mu^{exp} - a_\mu^{SM} = 287\ (80) \times 10^{-11}$ → > 3σ
  - Note this is larger than the EW contribution!



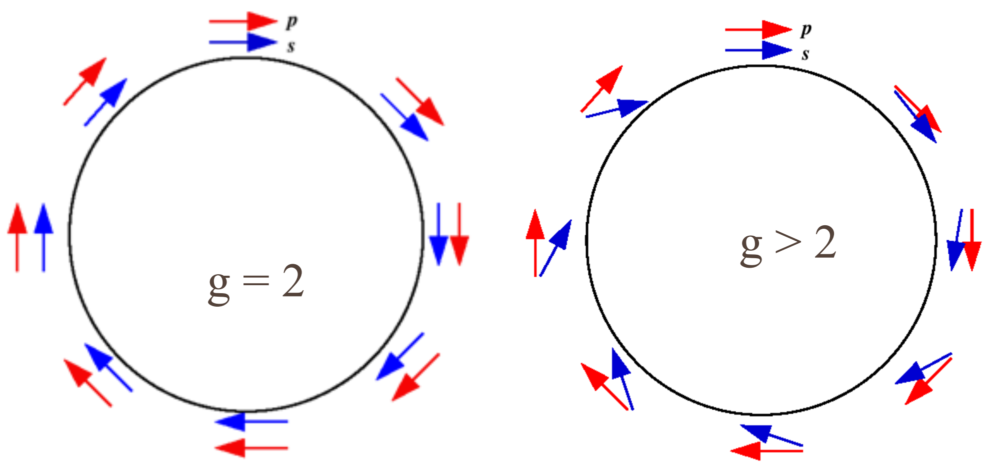
- Theorists working hard to reduce errors!
- New experiment needed

Davier, ICFA 2011

Measuring g-2

- Nature allows us to exploit certain properties
  - Can measure a_μ directly using cyclotron frequency and Larmor precession frequency

$$\omega_c = \frac{eB}{mc} \qquad \omega_s = g\frac{eB}{2mc}$$



$$\begin{aligned}\omega_a &= \omega_s - \omega_c, \\ &= \frac{eB}{mc}\left(\frac{g}{2} - 1\right), \\ &= \frac{eB}{mc}\frac{g-2}{2}, \\ &= a_\mu \frac{eB}{mc},\end{aligned}$$

Vertical confinement

- One problem with storage rings – How do you confine the muons?
  - Apply an electric field, which modfies this equation:

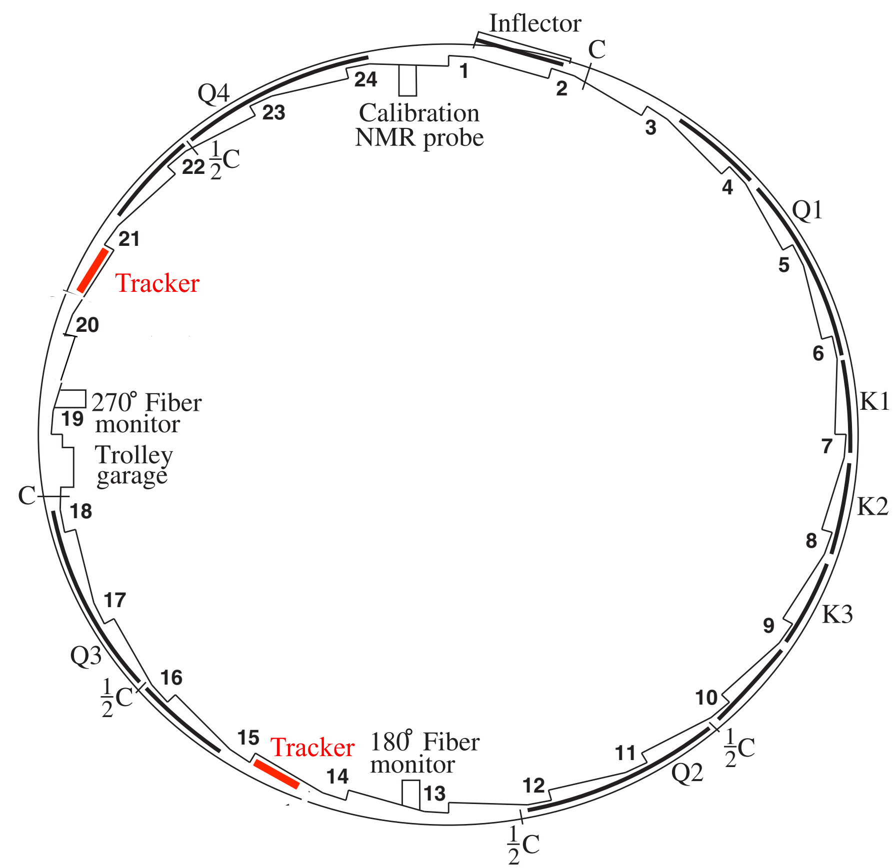
$$\vec{\omega}_a = \frac{e}{m}\left[a_\mu \vec{B} - \left(a_\mu - \frac{1}{\gamma^2 - 1}\right)(\vec{\beta} \times \vec{E})\right]$$

- Great, now we have a more complicated measurement
  - But we have another trick up our sleeves: “magic momentum”
  - By choosing the “magic momentum”, the coefficient in front of the E – field vanishes

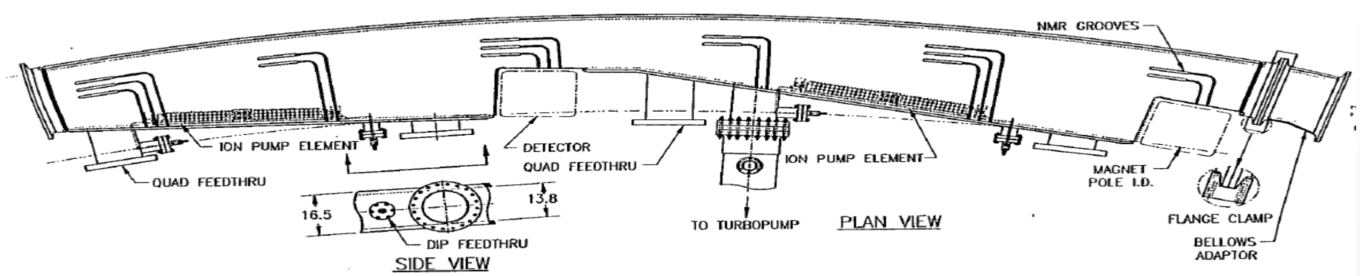
$$\gamma = 29.3\ ,\ p_\mu = 3.09\ \mathrm{GeV/c}$$

Measuring g-2

- Store muons in uniform field
- Measure the magnetic field using NMR probes (B)
- Count decay positrons to get precession frequency (ω_a)



$$\omega_a = a_\mu \frac{eB}{mc}$$



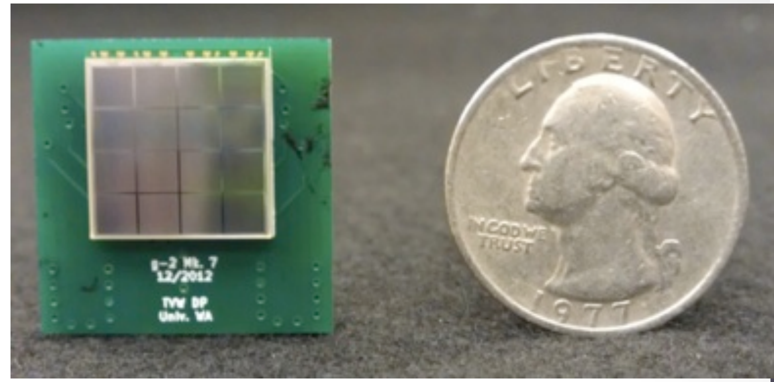
Improvements For E989

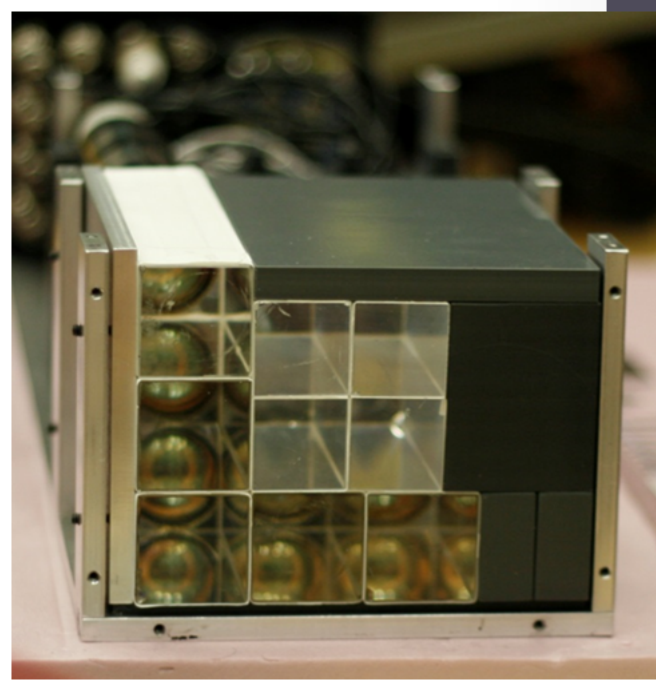
- Longer beam line reduces "hadronic flash" and allows for more muons
- Improved detectors

E821 Error	Size [ppm]	Plan for the New $(g-2)$ Experiment	Goal [ppm]
Gain changes	0.12	Better laser calibration and low-energy threshold	0.02
Lost muons	0.09	Long beamline eliminates non-standard muons	0.02
Pileup	0.08	Low-energy samples recorded; calorimeter segmentation	0.04
CBO	0.07	New scraping scheme; damping scheme implemented	0.04
E and pitch	0.05	Improved measurement with traceback	0.03
Total	0.18	Quadrature sum	0.07

Calorimeters

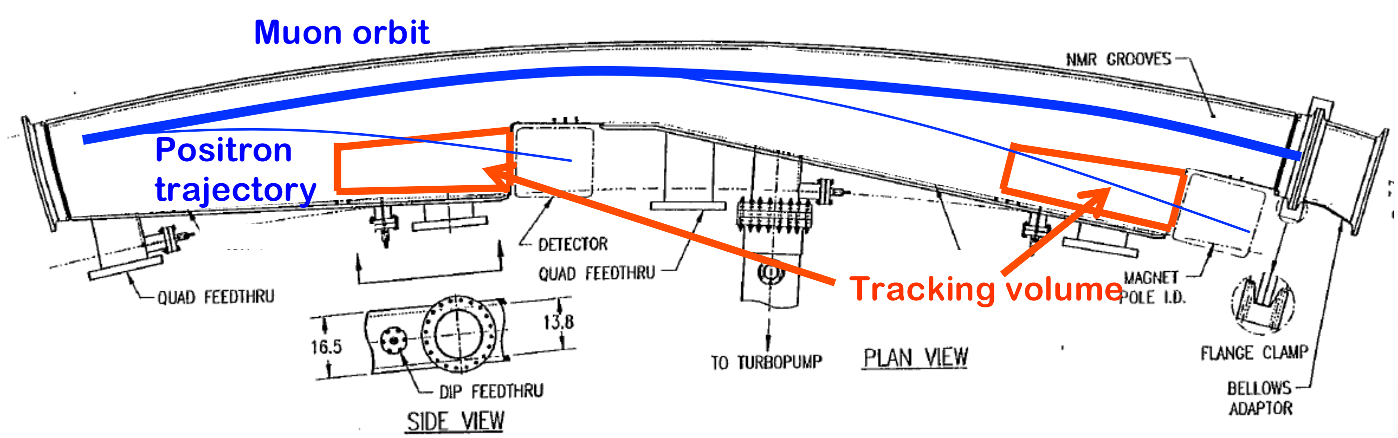
- Measures time and position
- PbF2 Crystals
  - Readout: SiPMs
  - Segmented (improve separation)
- Conducted a beam test (T1005) with segmented calorimeter
- Second beam test at SLAC in July





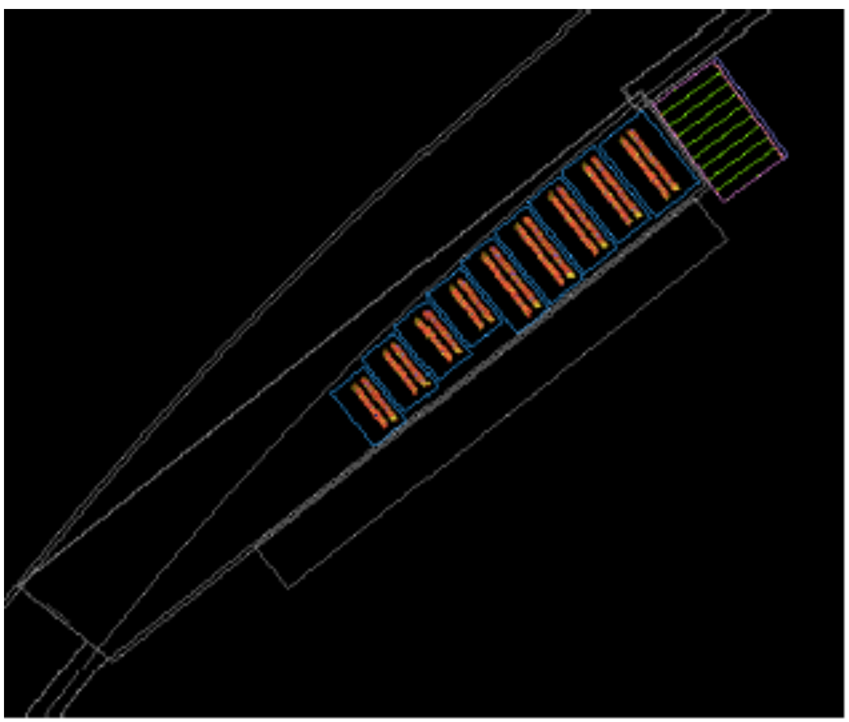
Tracking in g-2

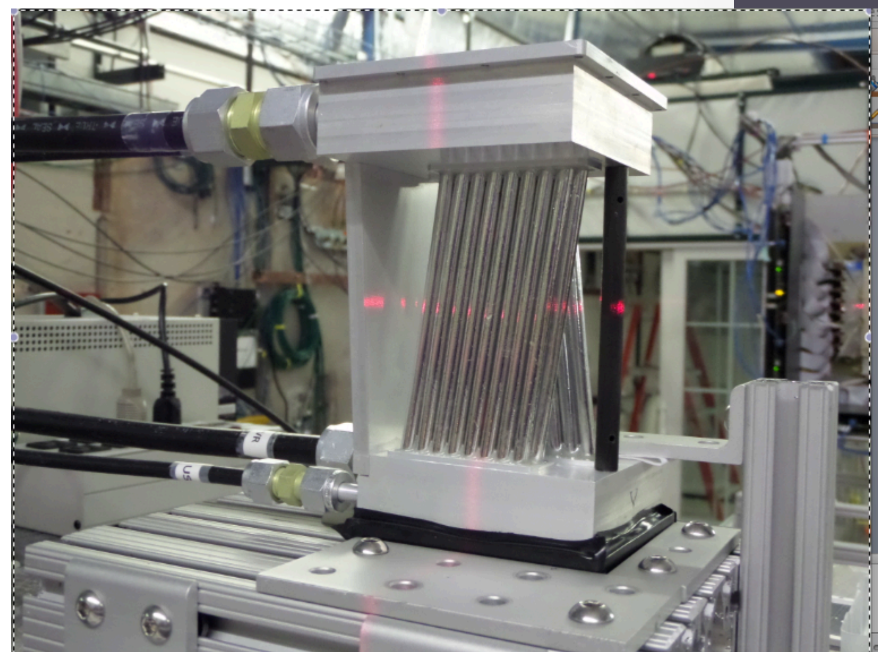
- Deviations from uniform circular motion lead to ppm level corrections to the precession frequency
- Need a clear picture of the muon beam to correct for these effects
- Constraints: Located in vacuum, minimal impact on B field



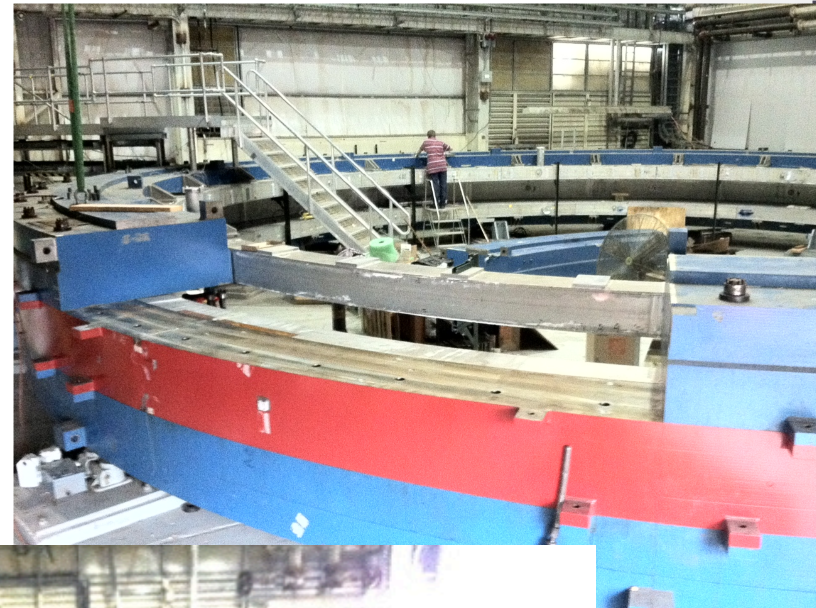
g-2 Tracker Design

- Mylar straws metalized with Al on outside and Au/Al on the inside.
- U-V doublet planes – 7.5 degrees from vertical
- Inside the vacuum (10^{-6} Torr)



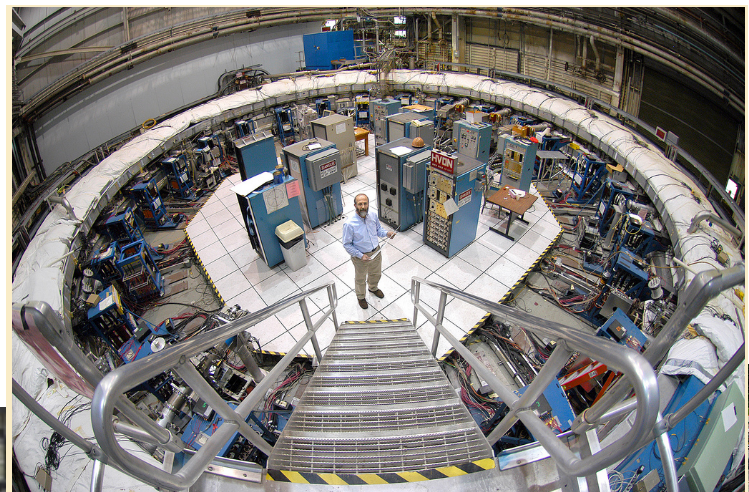


Reuse BNL Ring

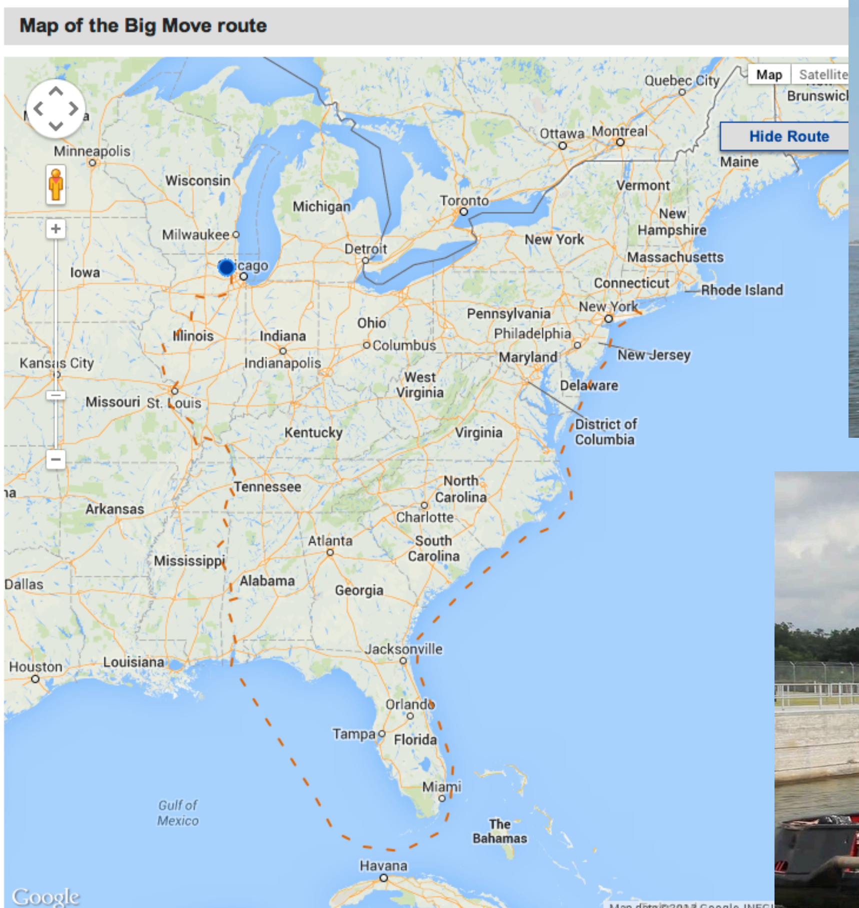


Moving the Ring

- Super conducting coils had to moved in one piece
    - One side couldn't twist more than 3mm respective to another side



By Land and Sea



Arrived!

MC-1

MC-1

Conclusions

- The ring has arrived at Fermilab and our building is almost complete
- The detector group is busy testing and finalizing designs for the new detectors

Looking forward to presenting results in the near future!

Backups

g-2: Theory Work

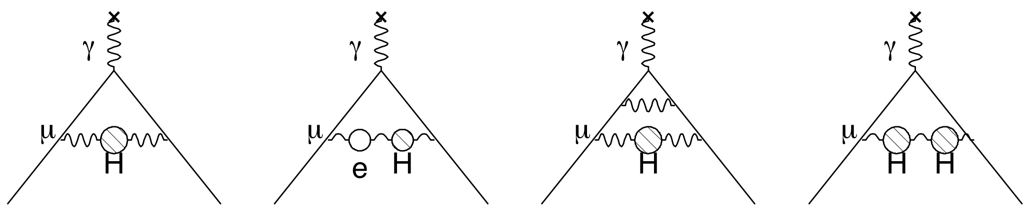
- Much progress has been made since the difference between theory and experiment was first shown by the BNL g-2 experiment
- The two largest uncertainties in the theory calculation:
  - Hadronic Vacuum Polarization
  - Hadronic Light by Light

CONTRIBUTION	RESULT IN 10^{-11} UNITS
QED (leptons)	$11\ 6584\ 718.09 \pm 0.14 \pm 0.04_{\alpha}$
HVP(lo)	$6\ 908 \pm 39_{\text{exp}} \pm 19_{\text{rad}} \pm 7_{\text{pQCD}}$
HVP(ho)	$-97.9 \pm 0.9_{\text{exp}} \pm 0.3_{\text{rad}}$
HLxL	105 ± 26
EW	$152 \pm 2 \pm 1$
Total SM	$116\ 591\ 785 \pm 51$

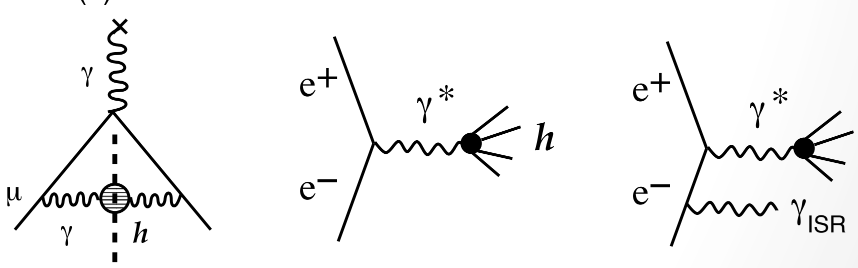
*Courtesy E. De Rafael, arXiv 0809.3025

g-2: Theory Work

- Hadronic Vacuum Polarization (LO)
  - Current uncertainty is ~ 0.5% (from experiments)
    - Additional data from VEPP-2000, BELLE, BES-3
  - Development: Lattice already at 5%
    - In 5 years, expecting to reduce this error to ~ 1-2%



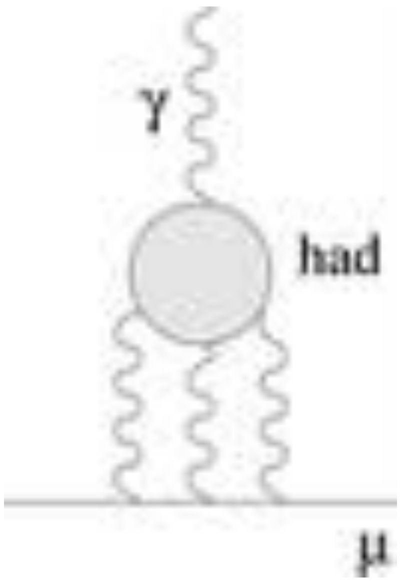
(a) (b) (c) (d)



(a) (b) (c)

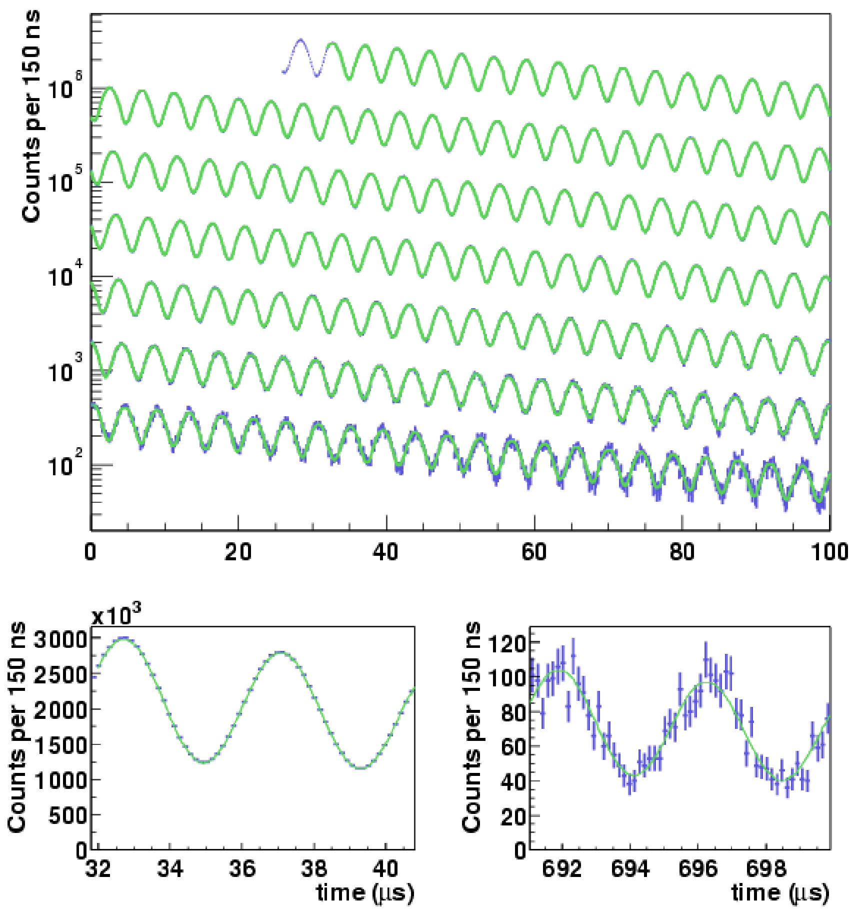
g-2: Theory Work

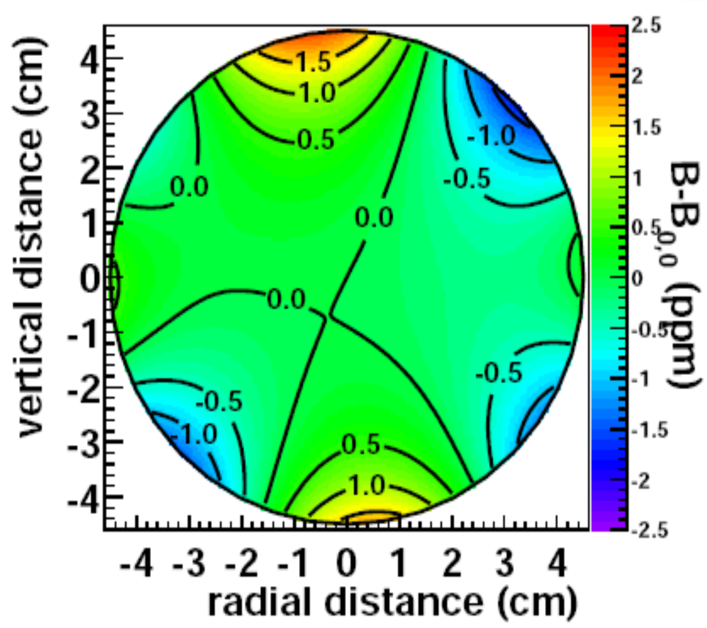
- Hadronic Light by Light
  - Current uncertainty is about ~ 25% (from models)
  - Development: Lattice initiatives targeting HLBL
    - In 5 years, possibly reduce this uncertainty to ~ 10%
    - Up to now, this is all theoretical work, now able to experimentally verify some models



Results from BNL E821

Final result: BNL aμ(exp) = 116 592 080(63) x 10^{-11}
Total statistical uncertainty: 0.46 ppm
Total systematic uncertaiinty: 0.28 ppm





Theoretical Calculation

- Normally the Hadronic part is broken up into 3 pieces:
  - Hadronic Vacuum polarizations (LO)
  - HVP (Higher order)
  - Hadronic Light by Light

$$a_\mu^{QED} = (11\,658\,471.809 \pm 0.015) \times 10^{-10}$$

$$a_\mu^{had} = (693.0 \pm 4.9) \times 10^{-10}$$

$$a_\mu^{weak} = (15.4 \pm 0.2) \times 10^{-10}$$

LO vacuum polarization	:	692.3 ± 4.2
HO vacuum polarization	:	-9.8 ± 0.1
LBL	:	10.5 ± 2.6

Upgrades to the Accelerator Complex

- Need 21 times more statistics compared to BNL
- Upgrade to the accelerator complex to 15Hz
  - Allows us to run with Nova

- Recycler
  - 8 GeV protons from Booster
  - Re-bunched in Recycler
  - New connection from Recycler to P1 line (existing connection is from Main Injector)
- Target station
  - Target
  - Focusing (lens)
  - Selection of magic momentum
- Beamlines / Delivery Ring
  - P1 to P2 to M1 line to target
  - Target to M2 to M3 to Delivery Ring
  - Proton removal
  - Extraction line (M4) to g-2 stub to ring in MC1 building